

The University of Chicago

A STUDY OF THE
SPECTRUM VARIABLES OF TYPE A

A PART OF A DISSERTATION SUBMITTED TO THE
FACULTY OF THE DIVISION OF THE PHYSICAL
SCIENCES IN CANDIDACY FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

DEPARTMENT OF ASTRONOMY AND ASTROPHYSICS
1946

By
ARMIN J. DEUTSCH

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Yerkes Observatory

Received November 16, 1946

ABSTRACT

The periods of variation have been found for the five spectrum variables BD $-18^{\circ}3789$, BD $+33^{\circ}1008$, π Boo(A), χ Ser, and γ Ari(S); the last three named have been newly discovered. Other new spectrum variables described are 78 Vir, 56 Ari, and 45 Her. Reproductions of spectrograms are given which illustrate the variation. The companions of the spectrum variables π Boo(A) and 17 Com(A) have been found to be metallic-line stars. A catalogue of spectrum variables has been compiled, which gives the gross spectroscopic characteristics of all such stars now known. The phase relations among lines originating from different elements have been discussed and found to differ from star to star. The luminosities and colors of the A0p stars correspond approximately to type B8. In general, the peculiar A stars appear to be appreciably bluer than normal stars of equivalent spectral type and to lie about 1 mag. above the main sequence.

I. INTRODUCTION

The spectrum variables of type A are those A stars of constant brightness (within, say, one-tenth of a magnitude) whose spectra contain absorption lines which vary in intensity or appearance but which do not show the c-characteristic. The problem of the spectrum variables appears to be closely related to the larger problem of the classification of the A stars. The wide diversity of spectra encountered among stars of this type has been frequently remarked, and it has now been well established¹ that the spectra of type A cannot be arranged in the two-dimensional array which suffices for the classification of earlier and later types. It is probably of profound significance that in only two well-delimited regions of the spectral sequence does the two-dimensional array become inadequate: among the stars of type A, where the hydrogen lines dominate the spectrum, and among the stars of very late type, where the molecular bands are dominant.

An understanding of the physical conditions which produce this hitherto unexplained diversity of spectra may be expected to come from a study of the most anomalous cases, such as the "silicon" and "strontium" stars of the *Henry Draper Catalogue*. The physical parameters which characterize the atmospheres of these stars are known to be those which produce spectrum variability in a number of cases, and it seems not unlikely that a better knowledge of this phenomenon will lead to the solution of the wider problems involved in the interpretation of the spectra of type A.

Two approaches to the problem suggest themselves. One is a program of detailed study of the brightest members of the class: spectroscopic investigations, under the highest possible dispersion, of the nature and identification of the absorption lines and of the changes in radial velocity which may be present, together with photometric and spectro-photometric studies of the continuum and the changes which may occur in it. The other approach is a survey of as many spectrum variables as can be found, with the ultimate object of determining in what respects they are alike and in what respects unlike and with the hope of being able eventually to isolate the relevant physical factors which produce the extremely complex phenomena observed in detail.

The first type of investigation is typified by the work of O. Struve and P. Swings² on α^2 Canum Venaticorum. The only other spectrum variables which have been studied in any detail are ϵ Ursae Majoris, most recently by J. W. Swensson;³ BD $-18^{\circ}3789$, by

¹ W. W. Morgan, *Pub. Yerkes Obs.*, Vol. 7, Part III, 1934.

² *Ap. J.*, 98, 361, 1943.

³ *Ap. J.*, 99, 258, 1944.

W. W. Morgan;⁴ and 73 Draconis, also by Morgan.⁵ The second type of investigation has recently been rather neglected. Accordingly, it has seemed desirable to undertake a systematic search for new representatives of the class of spectrum variables.

A file of the peculiar A stars in the *Drapeer Catalogue*, compiled by Morgan, was consulted. From it an observing list was prepared which comprises all the peculiar A stars brighter than magnitude 6.0 and accessible at the Yerkes Observatory. The list also includes a few stars recognized by Morgan or others as having peculiar spectra, although not so noted in the *Drapeer Catalogue*. The list comprises sixty-one stars in all.

It is my purpose to find which of these sixty-one stars are spectrum variables and which are not; to describe the gross characteristics of the variation in each case where it is found; and to find the period of variation, if it be periodic, in each such case. The present paper is in the nature of a report on the progress made in this program, which is as yet far from completed.

II. THE OBSERVATIONAL MATERIAL

I have used a one-prism spectrograph attached to the 40-inch refractor of the Yerkes Observatory. A total of 83 observations have been made with a 6-inch camera and 269 observations with a 12-inch camera, during the interval from September, 1945, to August, 1946. An "observation" comprises one or more spectrograms (usually two), taken consecutively, of a single star. The 6-inch camera gives a dispersion of about 125 Å/mm at $H\gamma$ and was employed to give a spectrogram of good definition between λ 3900 and λ 4500; the spectrograms measure about 8.2 mm from $H\beta$ to $H8$ and were widened at the telescope to a width of 0.6 mm. The slit width was 0.25 mm, which projects to 0.039 mm, or 4.8 Å, on the plate. The exposure time was about 4 minutes for a star of magnitude 5.0; a second, longer exposure was frequently given, to be sure of sufficient density in the region below $H\epsilon$. The 12-inch camera gives a dispersion of about 60 Å/mm at $H\gamma$ and gives good definition over the same region as is covered by the 6-inch camera; the spectrograms measure 17 mm from $H\beta$ to $H8$ and were usually widened at the telescope to a width of 1.5 mm. The slit width was 0.096 mm, or 0.029 mm = 1.8 Å on the plate. The exposure time was about 15 minutes for a star of magnitude 5.0 or longer to get the region of K sufficiently dense. In order to facilitate the direct comparison of two spectrograms by superposing the plates, emulsions together, and juxtaposing the spectra, the usual comparison exposures were not impressed beside the stellar spectra. However, one comparison exposure on a neon lamp was impressed on each plate as a check against poor focusing.

The emulsion used was Eastman 103a-O, and all plates were developed in Eastman D-19 developer. Special care was taken to keep the plates of comparable density and contrast. The distribution of density in the continuum, however, depends sensitively upon the guiding; this effect is apparent in the reproductions given below.

In addition to the plates taken by myself, reference will be made to plates taken by other observers with the Bruce spectrograph attached to the 40-inch refractor. These plates were taken with two different 600-mm cameras and have a dispersion of about 30 Å/mm at λ 4500. Most of the plates were taken for radial-velocity determinations; a variety of emulsions was used. The Bruce plates will be distinguished by the letters "IB" and "IR," respectively, depending upon which camera was used. Reference will also be made to plates taken at the McDonald Observatory with the Cassegrain spectrograph and 82-inch reflector. Those plates taken with two quartz prisms and the 500-mm camera have a dispersion of 55 Å/mm at $H\gamma$ and will be designated by the letters "CQ." Plates taken with two glass prisms and the same camera have a dispersion of 28 Å/mm at $H\gamma$ and will be designated by the letters "CG." My own plates will be designated by the letter "a" if taken with the 6-inch camera and by the letter "b" if taken with the 12-inch camera. All the enlargements given below were made from β plates.

⁴ *Ap. J.*, 74, 24, 1931.

⁵ *Ap. J.*, 77, 77, 1933.

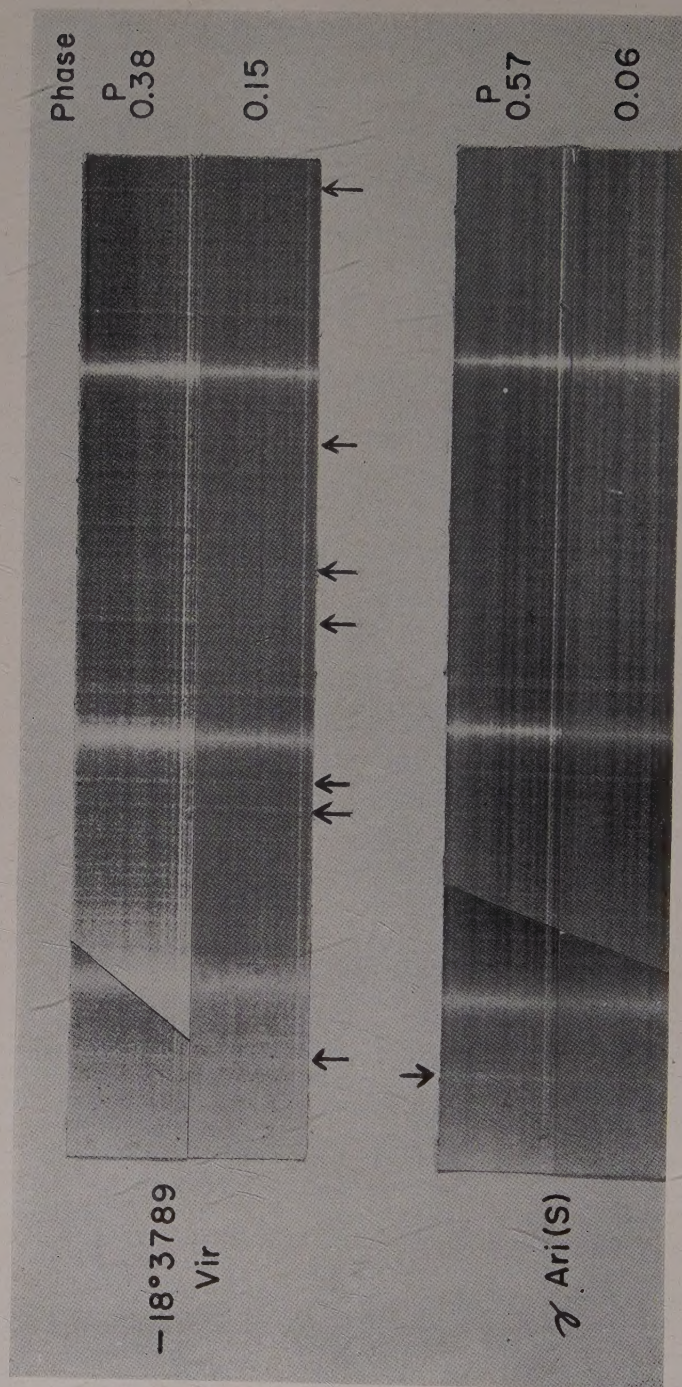


FIG. 1.—Intensity variations in two spectrum variables. In the spectra of $-18^{\circ}3789$ Vir, the lines marked are, from left to right, Ca II K, λ 4063 (unidentified), λ 4078 (Sr II + Cr II), Cr II 4171, Eu II, 4205, λ 4290 (unidentified), and Mg II 4481. In the spectra of γ Ari (S), Ca II K is marked.

III. OBSERVATIONS OF EIGHTEEN SPECTRUM VARIABLES

1. *BD-18°3789 Virginis = HD 125248*.—The star *BD-18°3789 Virginis* is classified A0p in the *Henry Draper Catalogue*, with the remark that λ 4128 and λ 4131 are strong. The spectrum bears some resemblance to that of α^2 CVn but is richer under moderate dispersion. The *Si* II doublet at $\lambda\lambda$ 4128–4131 is somewhat stronger in α^2 CVn, and the lines of *Cr* II are weaker.

Large changes in the intensities of absorption lines in the spectrum of *BD-18°3789* were discovered by W. W. Morgan,³ who found that the lines of *Eu* II exhibited periodic changes in strength, while those of *Cr* II varied in the opposite sense. An unidentified line at λ 4296 was found to vary with *Eu* II, and *Cr* I 4254 was found to vary with *Cr* II. Possible changes in the lines of *H* and *Mg* II were also noted.

Examination of 13 β plates and 25 CQ plates taken during 1944–1945 confirms the very large changes which occur in the lines of *Eu* II and *Cr* II. The elements of variation are found to be

$$Eu \text{ II maximum} = Cr \text{ II minimum} = JD\ 2430143.07 + 9.295 E;$$

TABLE 1

CRITERIA FOR ESTIMATES OF LINE INTENSITIES IN SPECTRUM OF *BD-18°3789 VIR*

Criterion	Definition	Scale
I.	λ 3930/ λ 3933	1, λ 3930 < < λ 3933; 4, λ 3930 = λ 3933; 6, λ 3930 > λ 3933
II.	λ 4063/ λ 4078	1, λ 4063 < < λ 4078; 4, λ 4063 = λ 4078; 7, λ 4063 > > λ 4078
III.	λ 4205/ λ 4233	1, λ 4205 < < λ 4233; 4, λ 4205 = λ 4233; 7, λ 4205 > > λ 4233
IV.	λ 4481	1, λ 4481 invisible; 7, λ 4481 strongest
V.	$0.2(2A+2B+C)$	1.0–6.6
VI.	Morgan's estimates	1.2–6.7 (see text)

and other variable lines have the same period. The lines *Ca* II K and *Mg* II 4481 vary with *Cr* II, and so do lines at $\lambda\lambda$ 4078, 4161, 4215, and 4290. The first three of these lines are probably due mainly to *Sr* II, although *Cr* II contributes to λ 4078 and λ 4215. The line λ 4290 is due partly to *Cr* I; the relative weakness of the other two strong components of the *Cr* I resonance multiplet at λ 4254 and λ 4275 makes it appear probable that there is another important contributor to λ 4290. The variation of the unidentified line at λ 4296 with *Eu* II is confirmed, and a very strong unidentified line at λ 4063 is found to vary in the same sense. Lines of *Si* II and *Fe* II probably vary with *Cr* II. Representative β plates are reproduced in Figure 1.

In order to derive the period of variation, estimates of line strength were made as given in Table 2. It was found convenient to employ one or more different criteria for different sets of plates; the criteria listed in Table 2 are defined in Table 1. Criterion VI was derived from Morgan's estimates⁶ of λ 4205 and λ 4558 by inverting his scale for λ 4558, applying appropriate scale factors, and adding. It should be understood that, when a ratio is given as the criterion, the notation is only symbolic, so that when criterion I is given as 6, for example, the notation does not mean that λ 3930 is six times as strong as λ 3933. In Figure 2 there is plotted for each of 53 plates the spectral characteristic according to the criterion of highest number given in Table 2.

The true form of the variation-curves can be better inferred from Figure 3, in which single criteria are plotted separately for the CQ plates only and which therefore present a more nearly homogeneous set of data. The curves for criteria I, II, and III agree in

⁶ *Ibid.*, p. 27.

TABLE 2
OBSERVATIONS OF BD-18°3789 VIR=HD 125248

PLATE	JD 2400000.00+	PHASE* P	SPECTRAL CHARACTERISTICS					
			Criterion					
			I	II	III	IV	V	VI
IR 8774.....	25309.94	0.029	.....	.....	6	.....	.....	.....
8786.....	25310.84	.125	.....	.....	6	.....	.....	.....
8797.....	25323.88	.528	.....	.....	1	.....	.....	.....
• 9595.....	26355.98	.566	.....	.....	.....	.....	.....	1.5
9601.....	26357.98	.781	.....	.....	.....	.....	.....	5.5
9606.....	26358.97	.890	.....	.....	.....	.....	.....	6.0
9618.....	26366.98	.750	.....	.....	.....	.....	.....	4.1
9621.....	26367.95	.855	.....	.....	.....	.....	.....	6.7
9628.....	26375.94	.715	.....	.....	.....	.....	.....	3.2
9634.....	26377.97	.932	.....	.....	.....	.....	.....	3.9
9643.....	26381.93	.358	.....	.....	.....	.....	.....	1.2
9648.....	26386.93	.895	.....	.....	.....	.....	.....	5.9
10515.....	27107.97	.469	.....	.....	1	.....	.....	.....
10925.....	27457.96	.122	.....	.....	5	.....	.....	.....
12081.....	28244.91	.787	.....	.....	5	.....	.....	.....
CQ 806.....	30126.74	.243	1	1	1	.....	1.0	.....
819.....	30133.77	.000	3	6	7	2	5.0	.....
823.....	30134.74	.104	3	6	7	3	5.0	.....
830.....	30135.72	.210	2	3	4	4	2.8	.....
831.....	30139.68	.636	1	1	1	4	1.0	.....
832.....	30140.63	.739	1	2	2	3	1.6	.....
835.....	30141.62	.845	2	5	3	4	3.4	.....
836.....	30141.68	.851	2	6	2	3	3.6	.....
837.....	30142.75	.965	5	7	5	2	5.8	.....
838.....	30143.75	.073	6	6	7	2	6.2	.....
839.....	30144.71	.176	4	5	3	3	4.2	.....
840.....	30144.78	.184	3	6	6	4	4.8	.....
900.....	30205.61	.729	1	1	1	.....	1.0	.....
1288.....	30381.98	.703	1	1	.....	.....	1.0	.....
1289.....	30382.01	.707	1	2	1	7	1.4	.....
1290.....	30382.04	.710	1	2	1	6	1.4	.....
1307.....	30384.01	.922	5	6	5	2	5.4	.....
1319.....	30385.02	.030	3	6	7	1	5.0	.....
2161.....	30897.66	.182	3	5	6	6	4.4	.....
2168.....	30898.65	.289	2	3	2	6	2.4	.....
2173.....	30899.67	.399	1	1	1	6	1.0	.....
2180.....	30900.64	.503	1	1	1	7	1.0	.....
2187.....	30902.64	.718	1	1	1	7	1.0	.....
2193.....	30903.66	.829	3	5	5	5	4.2	.....
2199.....	30904.61	.930	5	6	.....	.....	5.5	.....
β 42.....	31919.83	.151	.....	5.5	.....	.....	.....	.....
45.....	31921.72	.354	.....	3.0	.....	.....	.....	.....
46.....	31922.82	.474	.....	2.0	.....	.....	.....	.....
48.....	31936.67	.966	.....	6.5	.....	.....	.....	.....
50.....	31937.66	.070	.....	6.0	.....	.....	.....	.....
51.....	31937.82	.087	.....	5.5	.....	.....	.....	.....
62.....	31969.74	.521	.....	1.0	.....	.....	.....	.....
65.....	31975.70	.163	.....	5.5	.....	.....	.....	.....
70.....	31996.65	.417	.....	1.0	.....	.....	.....	.....
72.....	31998.61	.626	.....	1.0	.....	.....	.....	.....
76.....	32003.62	.167	.....	5.0	.....	.....	.....	.....
78.....	32005.61	.381	.....	2.0	.....	.....	.....	.....
82.....	32007.61	0.596	.....	1.0	.....	.....	.....	.....

* Eu II maximum = Phase 0 = JD 2430143.07 + 9.295 E.

the main, and there are probably no significant differences among them. The curve for the mean criterion, V, is somewhat smoother than the others, as was to be expected. All the curves indicate an abrupt change in the spectrum near phases $0^{\circ}2$ and $0^{\circ}8$ after *Eu* II maximum. There appears to be a real difference in the forms of the two extremes, the minima being in all cases very flat while the maxima are rather more rounded. In the cases of criteria I, II, and III the true ratios of equivalent widths vary enormously, and there is a tendency to assign the extreme value which the scale of estimation admits whenever the true ratios differ greatly from unity. That this effect is at work is suggested by the fact that the true ratios deviate most from unity when criteria I, II, and III are at their minima, and that is just where the flatness is most pronounced. In an attempt to assess the importance of this effect, the plates at minimum phases have been intercompared, but no differences were found which were related to phase. It is concluded that the almost rectangular minimum is probably real, although possibly exaggerated by the method of estimation, and that the variation is certainly anharmonic. This point may be further clarified by actual microphotometry of the changing lines, and the writer hopes to undertake this in the near future.

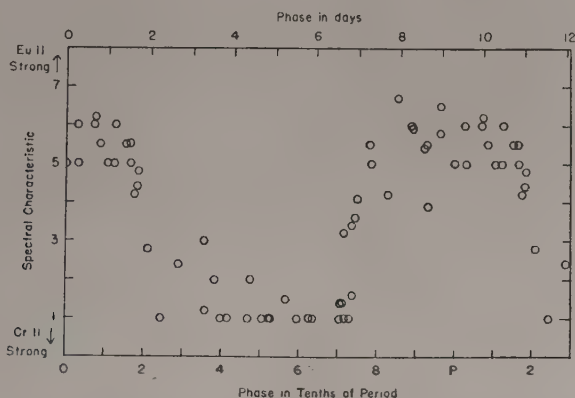


FIG. 2.—Variation of line intensities in the spectrum of BD $-18^{\circ}3789$. Each point represents a single plate. The phases have been calculated from the elements, Phase = 0 at JD 2430143.07 + 9.295 E.

The object BD $-18^{\circ}3789$ is situated so far south that plates cannot be obtained which are separated by more than 6 hours on a single night. The periods near 1 day which are reciprocal to the adopted period⁷ have been investigated, and the curves so derived show appreciably greater scatter. However, the possibility that the period is actually very nearly 1 day cannot be entirely eliminated until the elements are checked at another longitude.

2. *BD + 33°1008 Aurigae = HD 34452*.—The *Draper* type of this star is A0p, the noted peculiarity being the strength of *Si* II 4128–4131. These lines are stronger than in any other spectrum which I have observed. Other marked peculiarities include lines in the positions of *Sr* II 4078 and *C* II 4267, an unidentified line of moderate strength at λ 4057, and strong unidentified lines at $\lambda\lambda$ 3955, 3992, and 4200. The last three lines occur together in a number of the peculiar A stars and may well have a common origin. The strength of *Ca* II K is appropriate to a normal spectrum of type B9. The spectrum does not resemble closely that of any other known spectrum variable. Representative spectrograms are shown in Figure 4.

A further peculiarity is the appearance of a strong line at λ 4026 and another, weaker

⁷ O. Struve, *Pop. Astr.*, 36, 411, 1928.

line at λ 4471, both undoubtedly due to *He* I. Miss C. Westgate⁸ discovered that these two lines varied in strength, and she suspected certain other lines of changing. Thirteen β plates confirm the changes in the lines of *He* I and reveal that *Ca* II K changes with *He* I and that λ 4481 of *Mg* II and λ 4267 probably vary in the same sense. The lines $\lambda\lambda$ 3955, 3992, 4200, and 4057, and probably *Fe* II 4233, change in the opposite sense.

From the 13 β plates and from 27 CQ plates taken during 1944 it has been found that the elements of variation are

$$\text{He I maximum} = \text{JD } 2431334.90 + 2.4660 \text{ E};$$

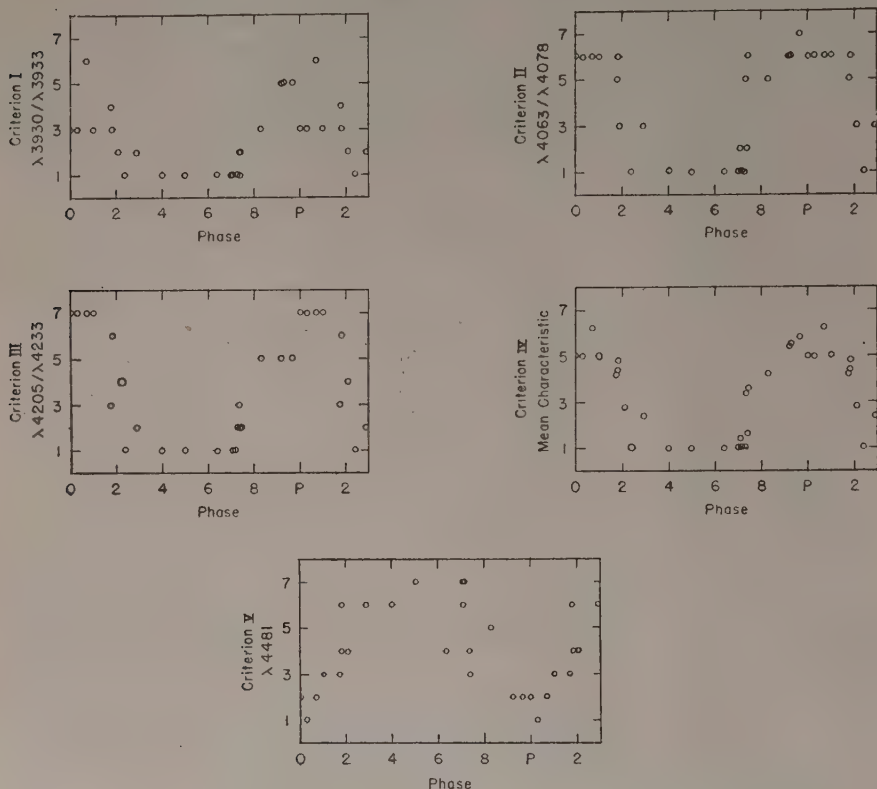


FIG. 3.—Variation of line intensities in the spectrum of BD-18°3789. Each point represents a single CQ plate. The phases have been calculated from the elements, Phase = 0 at JD 2430143.07 + 9.295 E.

the periods near 1 day have been eliminated. Figure 5 shows the variations of the *He* I lines with phase; the estimates on which it is based are given in Table 3, and the criteria used are defined at the foot of the table. The curve of variation is definitely asymmetrical, with the decline of the *He* I lines appreciably steeper than their rise and with the minimum flatter and broader than the maximum.

3. π Bootis(A) = HD 129174, and α Andromedae = HD 358.—The star π Boo is classified A0 in the *Draper Catalogue* and is a visual binary. In the spectrum of component A, peculiar lines of moderate strength are present at $\lambda\lambda$ 3944, 3984, 4137, 4171, 4179,

⁸ *Ap. J.*, 77, 227, 1933.

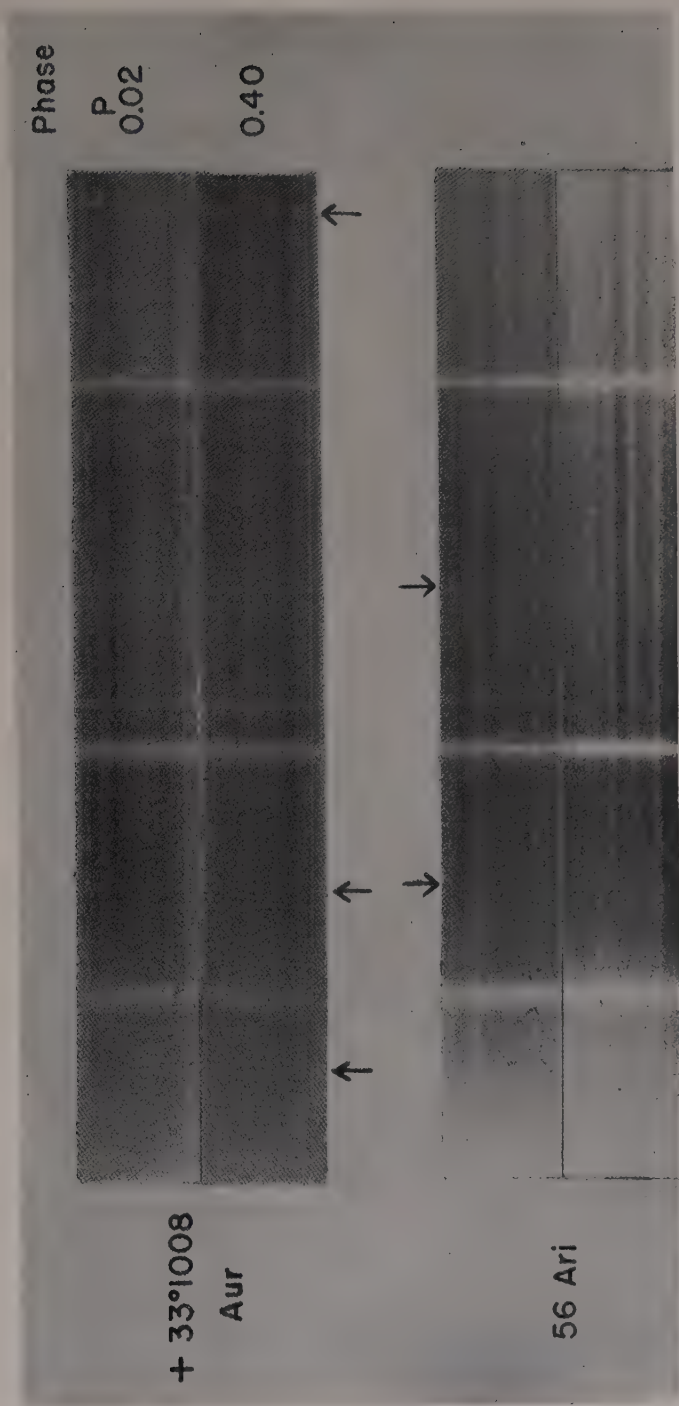


FIG. 4.—Intensity variations in two spectrum variables. In the spectra of +33°1008 Aur, the lines marked are *Ca* II K, *He* I 4026, and *He* I 4471. In the spectra of 56 Ari, the lines marked are *He* I 4026 and λ 4200 (unidentified).

4206, 4253, and 4282.⁹ Morgan¹⁰ has pointed out the close resemblance of the spectrum to that of α And, in which all these lines except λ 3984 are the same strength as in π Boo(A). The line λ 3984 is appreciably stronger in π Boo(A), and so is Ca II K. Representative spectrograms are shown in Figure 6.

From 9 β plates it is found that the K line in π Boo(A) suffers large changes in intensity. Other lines which change with K are λ 4137 and probably $\lambda\lambda$ 3944, 3984, and 4282; lines which change in the opposite sense are λ 4253 and probably λ 4206. The Si II doublet at $\lambda\lambda$ 4128–4131 is possibly less distinctly resolved when K is strong, suggesting the emergence of Eu II 4129; however, the β plates show none of the other strong Eu II lines.

The β plates were too few to permit the derivation of the period of variation; hence an attempt was made to accomplish this by referring to the Yerkes file of IB and IR plates

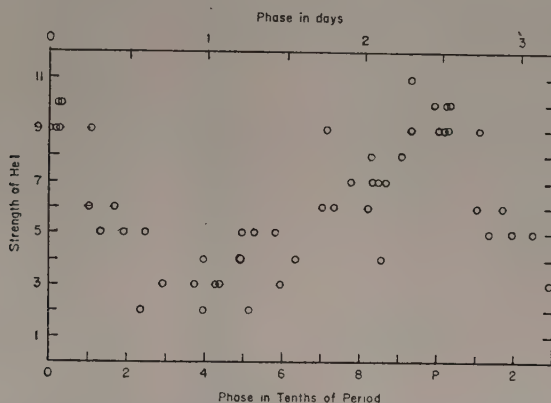


FIG. 5.—Intensity variation of $\lambda\lambda$ 4026 and 4471 of He I in the spectrum of BD +33°1008. Each point represents a single plate. The phases have been calculated from the elements, Phase = 0 at JD 2431334.90 + 2.4660 E.

taken at intervals between 1917 and 1932. These plates are poorly suited to the estimation of line intensities, for they differ greatly among themselves in density, contrast, and quality. Nevertheless, what seem to be real differences appear from plate to plate in the strengths of certain lines in the region best exposed, and most conspicuously at λ 4206. Accordingly, two independent estimates of the strength of this feature were made on each of 38 plates, and from the mean estimates the elements of variation were derived. These are

$$\lambda 4206 \text{ maximum} = \text{JD } 2421391.45 + 2.2445 \text{ E};$$

the periods reciprocal to the adopted one have been eliminated. The estimates are given in Table 4, and the scale of estimation is noted at the foot of the table. The curve of variation is given in Figure 7.

The scatter in Figure 7 is large, as was to be expected from the nonuniformity of the plates used, but the estimates seem to indicate a real variation with the adopted period. However, the variations in the K line exhibited by the β plates appear to be incompatible with this period. It is not impossible that K varies with a period different from

⁹ In the spectrum of κ Cancri, which closely resembles that of π Boo(A), Struve has identified (*A p. J.*, 99, 220, 1944) these lines as follows: λ 3944, Mn II; λ 3984, Fe I + Cr I; λ 4137, Mn II; λ 4171, Ti II; λ 4179, Fe II; λ 4206, Mn II; λ 4253, Cr II + Mn II; λ 4282, Mn II.

¹⁰ *A p. J.*, 73, 104, 1931.

that of $\lambda 4206$, but it is considered more probable that the period derived from the Bruce plates is illusory. A new series of spectrograms suitable for the estimation of line intensities will be required to resolve the problem; meanwhile, the period of 2.2445 days will be tentatively adopted.

TABLE 3
OBSERVATIONS OF BD+33°1008 AUR=HD 34452

PLATE	JD 2430000.00+	PHASE* <i>P</i>	STRENGTH OF He I		
			Criteria†		
			I	II	III
CQ 3686	1334.98	0.032	6	4	10
3697	1335.98	.438	1	2	3
3770	1352.88	.292	2	1	3
3775	1353.92	.714	5	4	9
3781	1354.87	.101	3	3	6
3786	1355.84	.495	2	3	5
3790	1356.85	.905	3	5	8
3802	1361.85	.929	6	3	9
3814	1363.82	.730	3	3	6
3826	1364.82	.134	3	2	5
3846	1367.87	.373	2	1	3
3865	1369.00	.831	5	2	7
3877	1369.83	.166	5	1	6
3881	1370.00	.236	1	1	2
3882	1370.02	.244	2	3	5
3894	1370.84	.525	3	2	5
3919	1373.81	.775	4	3	7
3923	1374.02	.864	4	3	7
3934	1374.83	.191	2	3	5
3938	1375.83	.596	2	1	3
3954	1376.87	.016	6	3	9
3971	1378.02	.486	2	2	4
3983	1378.84	.819	3	3	6
4007	1380.85	.632	2	2	4
4011	1381.02	.701	4	2	6
4022	1381.76	.000	5	4	9
4023	1381.82	.024	5	4	9
β 2	1724.79	.105	6	3	9
3	1732.91	.397	3	1	4
4	1738.94	.844	3	4	7
29	1863.67	.425	2	1	3
43	1920.61	.515	1	1	2
44	1921.63	.929	6	5	11
47	1936.58	.989	5	5	10
50	1937.58	.397	1	1	2
53	1941.59	.020	6	4	10
56	1948.58	.855	2	2	4
90	2021.88	.580	2	3	5
93	2023.89	.397	2	2	4
99	2029.89	0.826	4	4	8

* He I maximum = Phase 0 = JD 2431334.90 + 2.4660 E.

† Criteria:

I: $\lambda 4026/\lambda 4078$. 1, $\lambda 4026 < \lambda 4078$; 4, $\lambda 4026 = \lambda 4078$; 6, $\lambda 4026 > \lambda 4078$.

II: $\lambda 4471$. 1, $\lambda 4471$ invisible; 5, $\lambda 4471$ strongest.

III: I + II.

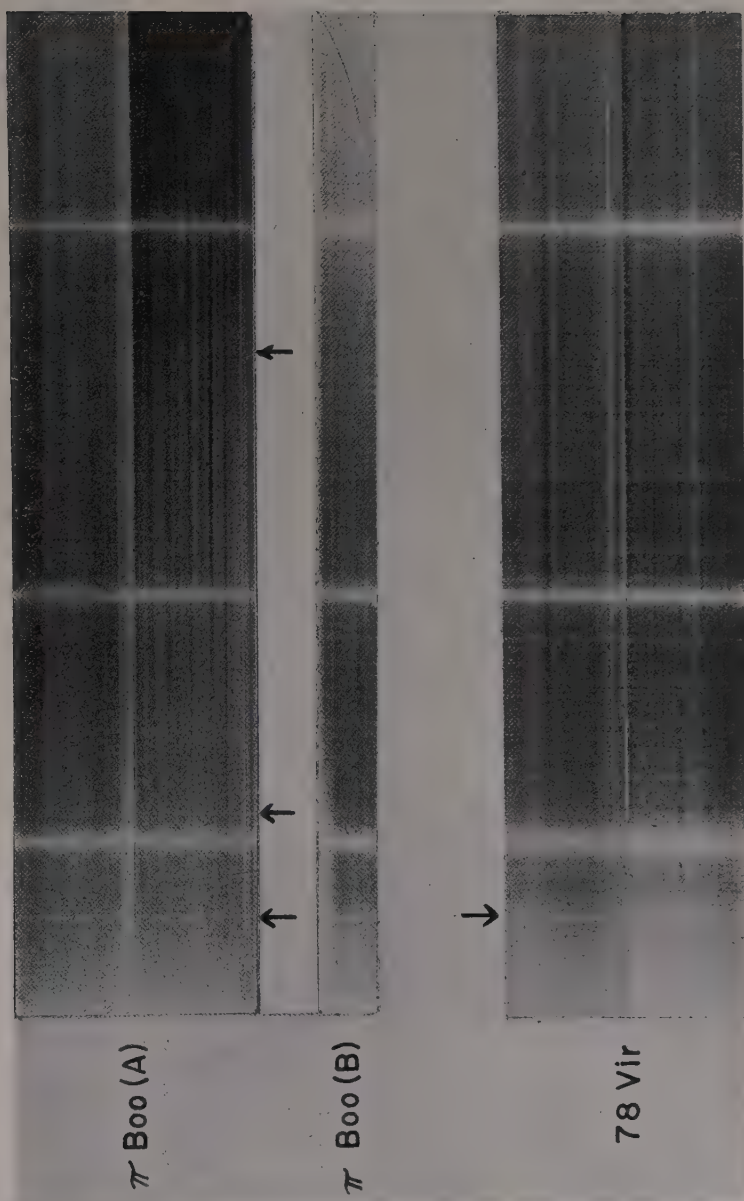


FIG. 6.—Intensity variations in two spectrum variables. In the spectra of π Boo (A), the lines marked are Ca II K, λ 3992 (unidentified), and Mn I 4253. The object π Boo (B) is a metallic-line star; the K line is much too weak for the lines of Fe I, Mn I, and Ca I. In the spectra of 78 Vir the K line is marked. The broad absorption feature at K in the lowest spectrogram is best seen by viewing the reproduction at arm's length.

While the period of variation remains uncertain, there can be little doubt that the variation is real and periodic. It is significant that N. Lockyer and F. E. Baxandall¹¹ and, later, P. Guthnick¹² found slight changes in the spectrum of α And; unfortunately, these writers have not given the wave lengths of the changing lines. In the spectrum of the same star, Ludendorff¹³ has noted changes in the appearance of $Mg\ II\ 4481$ and $H\gamma$.

TABLE 4
OBSERVATIONS OF π Boo(A)=HD 129174

PLATE	JD 2420000.00+	PHASE* <i>P</i>	STRENGTH† OF $\lambda\ 4206$		
			1st Estimate	2d Estimate	Mean
IB 4034.....	0565.78	0.237	2	1	1.5
4043.....	0566.99	.775	3	2	2.5
4047.....	0569.95	.094	2	2	2.0
4095.....	0593.70	.677	3	2	2.5
4122.....	0607.79	.951	4	3	3.5
4145.....	0628.71	.272	3	1	2.0
4168.....	0657.61	.151	1	1	1.0
4754.....	1239.99	.619	1	1	1.0
4778.....	1251.94	.942	3	3	3.0
4786.....	1254.00	.859	3	2	2.5
4793.....	1258.99	.085	3	1	2.0
4820.....	1279.90	.400	1	1	1.0
4828.....	1281.91	.294	2	1	1.5
4832.....	1283.86	.165	4	2	3.0
4835.....	1286.98	.557	2	3	2.5
4840.....	1309.80	.721	4	3	3.5
4848.....	1311.83	.628	2	2	2.0
4850.....	1314.96	.022	4	4	4.0
4861.....	1325.76	.834	2	2	2.0
4868.....	1328.75	.165	2	2	2.0
4877.....	1342.73	.392	1	3	2.0
4898.....	1358.77	.539	2	2	2.0
4917.....	1365.66	.610	1	1	1.0
4935.....	1391.60	.165	3	4	3.5
4949.....	1409.61	.192	3	3	3.0
5440.....	1983.92	.067	2	3	2.5
5466.....	2018.49	.468	1	1	1.0
5475.....	2028.80	.063	3	3	3.0
5489.....	2049.73	.388	1	1	1.0
5502.....	2076.68	.393	2	2	2.0
5505.....	2088.59	.699	3	3	3.0
5509.....	2091.64	.058	4	4	4.0
5513.....	2102.70	.869	4	4	4.0
5547.....	2161.62	.236	1	0	0.5
5556.....	2168.62	.456	1	1	1.0
6149.....	2777.74	.739	2	1	1.5
IR 10097.....	6811.65	.982	4	4	4.0
10115.....	6825.73	0.254	4	3	3.5

* $Mn\ II$ maximum = Phase 0 = JD 2421391.45 + 2.2445 E.

† 0, $\lambda\ 4206$ invisible; 4, $\lambda\ 4206$ strongest.

¹¹ *Proc. R. Soc., A*, **77**, 550, 1906.

¹² *A.N.*, **245**, 228, 1932.

¹³ *A.N.*, **176**, 327, 1907.

Kohl¹⁴ has confirmed these changes and has also found that K varies; he suspected changes in a number of other lines, particularly $\lambda 4026$ and $\lambda 4471$ of $He I$ and $\lambda 3984$. I have only three β plates of α And, and these seem to indicate that variation is present, notably in $\lambda 3984$ and $\lambda 4137$.

In the case of α And, Baxandall¹⁵ pointed out a number of coincidences with lines in the spark spectrum of manganese and concluded that, among the stronger peculiar lines, those at $\lambda\lambda 3944, 4137, 4206, 4253$, and 4282 were due to "proto-manganese." Large differences in relative intensity between star and spark were noted and ascribed to excitation effects. Morgan has subsequently discussed¹⁰ the spectra of the stars like α And and has concluded that most of the peculiar lines are due to an ionized state of manganese. The four strongest lines of the multiplet $Mn II a^5F - z^5D$ agree in position with star lines, two of which are $\lambda 4206$ and $\lambda 4253$.

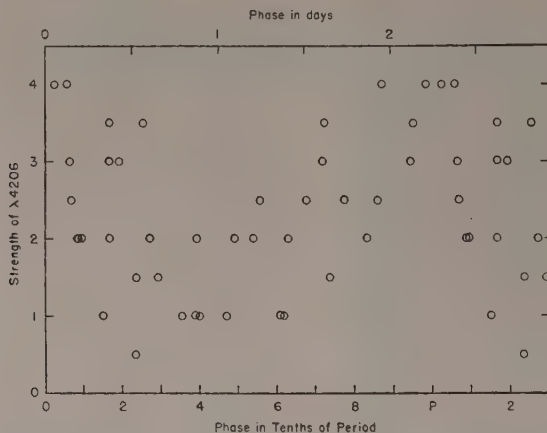


FIG. 7.—Intensity variation of $Mn II 4206$ in the spectrum of π Boo (A). Each point represents a single plate. The phases have been calculated from the (provisional) elements, Phase = 0 at JD 2421391.45 + 2.2445 E.

There can be no doubt that $Mn II$ accounts in part for the peculiarities of the spectra of stars like α And. However, Miss C. E. Moore's revised *Multiplet Table*¹⁶ gives no lines in the spectrum of $Mn II$ which could account for $\lambda 3944$, $\lambda 4137$, or $\lambda 4282$. Of these lines, the second varies out of phase with $Mn II 4253$, and the other two probably do the same. Since we know of no case in which lines originating from a given ion vary out of phase with one another, the evidence from the variation is that $\lambda\lambda 3944, 4137$, and 4282 probably do not originate from $Mn II$. It appears that a satisfactory discussion of the peculiar lines in the spectra of stars like α And must wait upon a more complete term analysis of $Mn II$ than is available at the present time.

The star π Boo(B) is 0.87 mag. fainter than A and $5''.8$ distant in position angle 105° . The position angle is increasing slowly; and Aitken¹⁷ states that the pair is probably a physical one, although the proper motions are widely divergent: $0''.016$ in $82^\circ.8$ for A, and $0''.020$ in $287^\circ.8$ for B.¹⁸ F. Leonard¹⁹ gives the spectral type of B (= HD 129175) as A5.

¹⁴ *A.N.*, **262**, 469, 1937.

¹⁵ *M.N.*, **74**, 250, 1914.

¹⁶ *A Multiplet Table of Astrophysical Interest* ("Contr. Princeton U. Obs.," No. 20 [1945]).

¹⁷ *New General Catalogue of Double Stars* (Washington: Carnegie Institution of Washington, 1932).

¹⁸ Dr. G. P. Kuiper writes: "The pair is definitely a physical one; the large difference between the Boss motions is spurious, as is obvious from the micrometer measures."

¹⁹ *Lick Obs. Bull.*, **10**, 169, 1923.

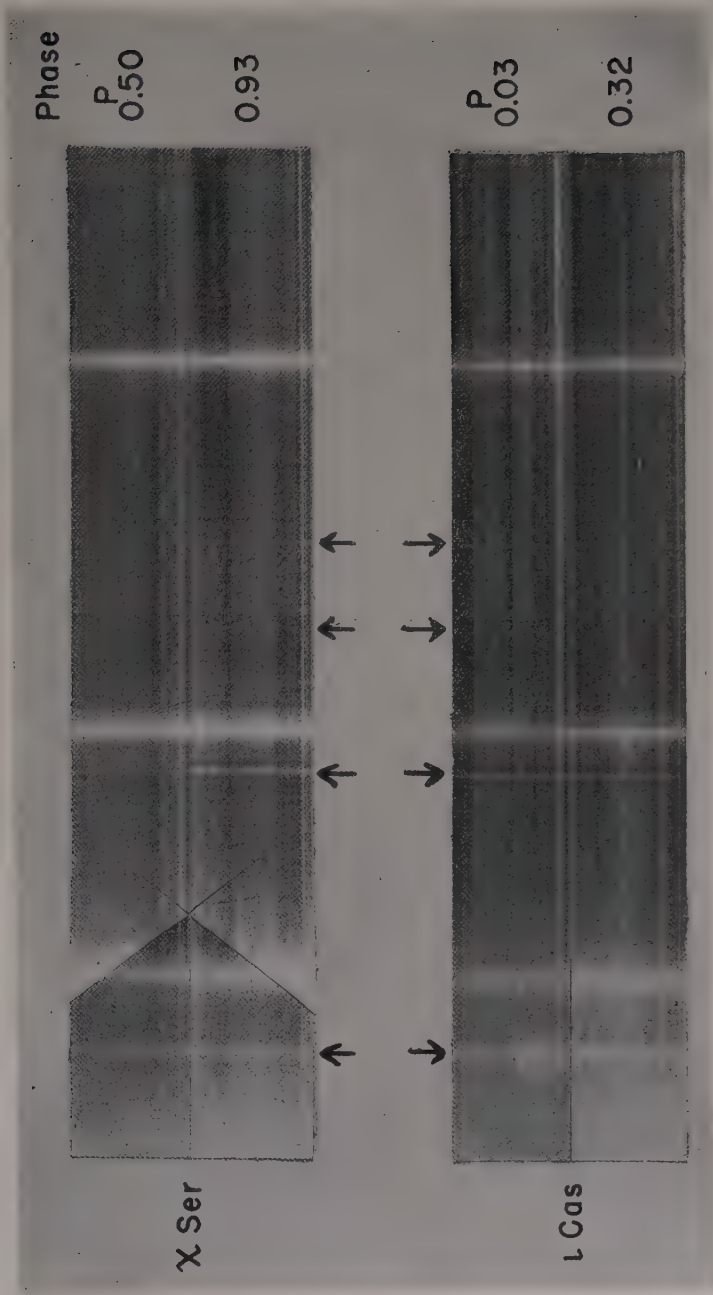


FIG. 8.—Intensity variations in two spectrum variables. In the spectra of X Ser, the lines marked are $Cu\ II\ 4078$, $\lambda\ 4161$ ($Sr\ II^2$), and $Sr\ II\ 4215$. In the spectra of L Cas, the same lines are marked. Note that K varies in phase with the other variable lines in L Cas, and out of phase in X Ser.

A β plate, reproduced in Figure 6, shows that it is a typical metallic-line star, with the K line indicating a type of A2 while the other metallic lines correspond to A7 or F0. This association of a spectrum variable with a metallic-line star is particularly interesting; it is observed also in the case of the chromium-europium star, 17 Comae (*q.v.*).

It is necessary to add that spectrograms of either component of π Boo are probably contaminated to some small extent by the light of the other. That the contamination cannot be sufficient, however, to produce the changes observed in the spectrum of A is readily concluded from an inspection of Figure 6.

4. χ *Serpentis* = HD 140160.—The spectrum of χ *Serpentis* closely resembles that of ι Cassiopeiae. Its *Draper* classification is A0p, the noted peculiarity being the strength of λ 4078. This line, with λ 4215, becomes considerably stronger than in ι Cas; K is always much weaker than in ι Cas; and lines at λ 4422 and λ 4489 are weaker than in ι Cas. Representative spectrograms are reproduced in Figure 8.

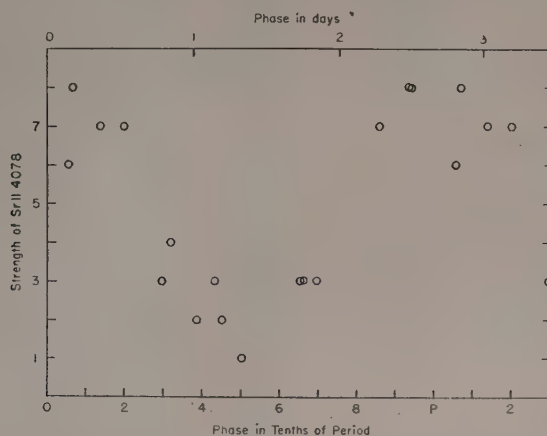


FIG. 9.—Intensity variation of Sr II 4078 in the spectrum of χ Ser. Each point represents a single plate. The phases have been calculated from the elements, Phase = 0 at JD 2432003.85 + 2.675 E.

From a study of 16 β plates, it is found that λ 4078 and λ 4215 exhibit large variations in intensity. The elements of variation are

$$Sr \text{ II maximum} = \text{JD } 2432003.85 + 2.675 E;$$

the periods reciprocal to the adopted one have not been eliminated. The curve of variation is indicated in Figure 9; it is based upon the estimates given in Table 5. These estimates were made by intercomparison of the β plates, which were arranged in order of increasing strength of λ 4078 and then assigned the numbers given in the table. The plates are too few to establish conclusively the nature of the variation-curve, but the present evidence indicates that it is very nearly harmonic.

Unidentified lines at λ 4161 and λ 4290 vary strongly in phase with the resonance doublet of Sr II, and K varies in the opposite sense. The amplitude of the variation in λ 4078 and λ 4215 is much greater than in ι Cas, and the amplitude of the variation in K is much less. It is remarkable that in ι Cas the lines of Sr II and Ca II vary together, while in χ Ser they change out of phase with each other.

5. γ *Arietis* (S) = HD 11503.—This star is classified A0p in the *Draper Catalogue*, with the remark that the Si II doublet at $\lambda\lambda$ 4128–4131 is strong. Guthnick²⁰ subsequent-

²⁰ *Sitz. Preuss. Akad. Wiss. Berlin*, No. 29, 1931.

ly called attention to the peculiarities of the spectrum and implied that he suspected it of varying. Morgan²¹ has identified *Eu* II 4205 in the spectrum. There is a close resemblance to the spectrum of BD-18°3789 at *Cr* II maximum, except that the lines of *Cr* II are somewhat stronger in the latter star. Representative spectrograms are reproduced in Figure 1.

TABLE 5
OBSERVATIONS OF χ SER=HD 140160

Plate	JD 2430000.00+	Phase* <i>P</i>	Strength of Sr II	Plate	JD 2430000.00+	Phase* <i>P</i>	Strength of Sr II
β 51.....	1937.83	0.318	4	β 82....	2007.72	.450	2
65.....	1975.76	.501	1	85....	2009.73	.198	7
68.....	1992.76	.854	7	88....	2021.64	.651	3
70.....	1996.61	.296	3	92....	2023.73	.430	3
72.....	1998.64	.052	6	94....	2025.61	.135	7
76.....	2003.69	.937	8	96....	2027.73	.929	8
78.....	2005.70	.693	3	98....	2029.68	.660	3
81.....	2006.79	.064	8	100....	2031.63	0.386	2

* *Sr* II maximum = Phase 0 = JD 2432003.85 + 2.675 E.

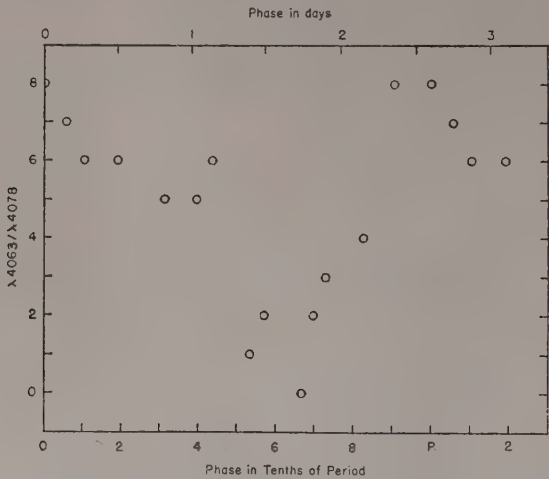


FIG. 10.—Intensity variation of the blends at λ 4063 and λ 4078 in the spectrum of γ Ari (S). Each point represents a single plate. The phases have been calculated from the (provisional) elements, Phase = 0 at JD 2431782.5 + 2.607 E.

Examination of 14 β plates reveals that at least some of the features which change in BD-18°3789 are also variable in γ Ari (S). Except in the case of the K line, the changes are of much smaller amplitude in the latter star, and the phase relations appear to differ between the two stars. On each of the β plates, the ratio λ 4063/ λ 4078 has been estimated twice; the estimates are given in Table 6, and they are plotted in Figure 10, according to the elements

$$Ca\ II\ minimum = Cr\ II\ minimum = JD\ 2431782.5 + 2.607\ E.$$

²¹ *Ap. J.* 75, 53, 1932.

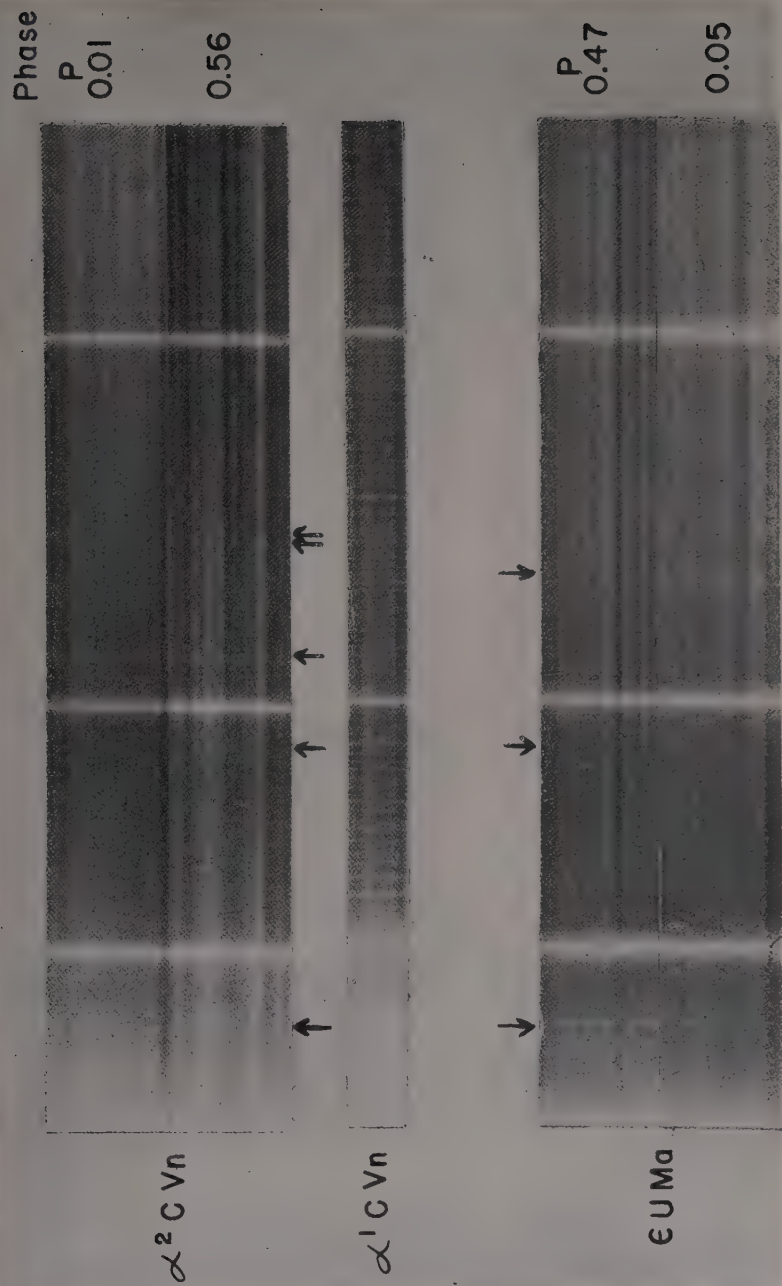


FIG. 11.—Intensity variations in two spectrum variables. In the spectra of α^2 CVn, the lines marked are Ca II K, λ 4078 (Sr II + Cr II), λ 4128-31 (Si II + Eu II), λ 4200 (unidentified), and Eu II 4205. α^1 CVn is of type F5 IV. In the spectrum of ϵ UMa, the lines marked are Ca II K, Cr II 4078, and λ 4179 (Fe II + Cr II).

The periods reciprocal to the adopted one have been eliminated; however, these elements are based on a small number of plates and require confirmation. There are too few plates to permit conclusions regarding the form of the variation-curve.

The star γ Ari (N) (= HD 11502) is 8'' distant in position angle 0° . Its spectrum is of type B9V and appears to be normal, although Guthnick²⁰ regards the K line as weak and excessively broad. The brightness of γ Ari (N) is 0.08 mag. greater than that of its peculiar companion, but the image configuration of the binary on the slit-jaws is such that there can be no question of the contamination of the spectrum of one component by the light of the other.

The two components of γ Ari have common proper motion and undoubtedly form a physical system.

6. *ι Cassiopeiae* = HD 15089.—The *Draper* type is A5p, and the lines of *Sr* II and *Cr* II are strong. The K line has been found²² to change its intensity by an amount equivalent to a change in type from about A2 to F0. The period of variation is 1.740 days, and

TABLE 6
OBSERVATIONS OF γ ARI (S)=HD 11503

PLATE	JD 2430000.00+	PHASE* P	λ 4063/ λ 4078			PHASE	JD 2430000.00+	PHASE* P	λ 4063/ λ 4078		
			1st Esti- mate	2d Esti- mate	Mean				1st Esti- mate	2d Esti- mate	Mean
β 10.....	1784.65	0.825	2	2	4	β 69.....	1992.88	0.698	1	1	2
17.....	1836.54	.729	2	1	3	74.....	1098.89	.000	4	4	8
28.....	1863.59	.103	.....	3	6	77.....	2003.85	.905	4	4	8
32.....	1869.56	.395	2	3	5	79.....	2005.84	.666	0	0	0
34.....	1871.63	.188	3	3	6	81.....	2006.85	.058	3	4	7
35.....	1872.53	.534	1	0	1	83.....	2007.84	.437	3	3	6
36.....	1874.56	0.314	2	3	5	92.....	2023.82	0.568	1	1	2

* *Cr* II minimum = Phase 0 = JD 2431782.5 + 2.607 E.

the resonance doublet of *Sr* II changes in phase with K. Examination of 10 β plates and 14 α plates confirms the published period, which is probably correct to within 0.001 day. From the β plates and from four CG plates taken in January, 1946, it is found that $\lambda\lambda$ 4133, 4161, 4199, 4423, and 4431 change with K; only λ 4179 among the stronger lines appears to vary in the opposite sense. A number of other lines probably vary with K, notably λ 4290 and the lines of *Cr* II. The CG plates show no trace of *Eu* II 4205. The lines of *Fe* II are quite strong, especially λ 4233; *Fe* I is present but weak. Representative spectrograms are shown in Figure 8.

7. *78 Virginis* = HD 118022.—The *Draper* classification of this star is A2p, with the remark that $\lambda\lambda$ 4128–4131 are strong and that the spectrum resembles that of θ' Microscopii. Except for a much weaker K line, the spectrum is very similar to that of *ι Cas*. The latter star does not show the lines of *Eu* II, however, and these are definitely present in 78 Vir, as Morgan²¹ has already shown. The lines of *Cr* II are also rather stronger in 78 Vir, as are *Fe* II 4233, and λ 4290 and λ 4423. The last-named line becomes very strong in 73 Draconis, which also resembles 78 Vir but is distinctly later in type.

Three β plates show changes in the spectrum of 78 Vir, the most pronounced variation being at *Ca* II K. When the K line is weak, it appears superposed over a diffuse absorption feature about 8A wide. This feature was first pointed out²³ by Morgan and his col-

²² Deutsch, *Ap. J.*, 103, 99, 1946.

²³ *An Atlas of Stellar Spectra* (Chicago: University of Chicago Press, 1943), p. 18.

laborators; it is not present when K is strong. The lines of *Cr* II and *Sr* II probably vary out of phase with K. The period of variation is unknown. The spectral changes are illustrated in Figure 6.

8. *56 Arietis* = *HD 19832*.—The star 56 Ari is especially interesting for the reason that it is the only known spectrum variable that has poor lines on plates of moderate dispersion. The *Draper* type is A0p, the peculiarity being a feature at λ 4129. From 10 β plates it is found that other peculiarities are *He* I 4026, which varies from complete invisibility to an intensity appropriate to type B8, and the unidentified lines at $\lambda\lambda$ 3955, 3992, and 4200, which seem to be stronger when λ 4206 is absent. The feature at λ 4129 also varies, probably in phase with the unidentified lines, and a very weak line in the position of *Cr* II 4078 probably changes in the same sense. The K line is extraordinarily weak. The period of variation is unknown; there is some evidence that it may be much shorter than that of any other known spectrum variable. Representative spectrograms are shown in Figure 4. The spectrum of BD+3°2867 Vir closely resembles that of 56 Ari.

9. *45 Herculis* = *HD 151525*.—The *Draper* type is A0p, with $\lambda\lambda$ 4128–4131 noted. The spectrum closely resembles that of ϵ UMa, except that *Mn* I 4030–4034 do not appear. From 6 β plates it is established that *Ca* II K varies and that *Mg* II 4481 probably varies with K, while the lines of *Cr* II probably vary in the opposite sense. The amplitude of variation appears to be somewhat smaller than in ϵ UMa; the period is unknown.

10. *49 Cancrī* = *HD 74521*.—The *Draper* type is A0p, and a resemblance to the spectrum of α Doradus is noted. The spectrum also resembles that of α^2 CVn, but K is much stronger. Other differences are in the *Si* II doublet $\lambda\lambda$ 4128–4131, in λ 4078 and λ 4215 of *Sr* II, and in *Fe* II 4233, all of which are appreciably stronger than in α^2 CVn. The line *Eu* II is present, as noted by Morgan.²¹ Three β plates do not reveal the changes in λ 4205 and λ 4215 reported by Morgan;²⁴ however, the number of plates is too small for conclusions to be drawn.

11. *17 Comae* = *HD 108662*.—The *Draper* type is A0p, and the spectrum is almost identical with that of 78 Vir. Morgan has reported²⁵ variations in certain lines of *Cr* II and *Sr* II. Four β plates reveal no certain changes, but this evidence is inconclusive.

A companion with common proper motion is 145'' distant in position angle 250°. This star is HD 108651, type A3, magnitude 6.69. A CQ plate taken by J. L. Greenstein in May, 1942, exhibits a spectrum of type about F2, but with the K line only as strong as in type A2. Certain other anomalies appear to be present in the spectrum.

12. *21 Comae* = *HD 108945*.—The *Draper* type is A3p, and the spectrum is nearly identical with that of ι Cas at *Ca* II minimum. Morgan²⁵ has reported variations in λ 4215. A study of 11 β plates suggests that most or all of the features which change in ι Cas are variable in this spectrum, but the changes are of much smaller amplitude and are not conclusively established by the β plates.

13. ϵ *Ursae Majoris* = *HD 112185*.—The *Draper* type is A0p, the noted peculiarities being the weakness of K and the strength of *Si* II 4128–4131. Six β plates reveal changes in K which conform to the period given by Guthnick.²⁶ Pronounced changes in the opposite sense occur in the lines of *Cr* II. Representative spectrograms are shown in Figure 11.

14. α^2 *Canum Venaticorum* = *HD 112413*.—The most exhaustively studied¹ of the spectrum variables, α^2 CVn is of type A0p; $\lambda\lambda$ 4128–4131 are strong. Six β plates exhibit changes which conform to the elements determined by Miss G. Farnsworth.²⁷ The most pronounced changes occur in λ 3930 and λ 4205 of *Eu* II and in *Ca* II K, which varies with *Eu* II; in *Cr* II 4078, *Fe* II 4233, and an unidentified line at λ 4200, all of which vary out of phase with *Eu* II.

²⁴ *Ap. J.*, **76**, 315, 1932.

²⁶ *Sitz. Preuss. Akad. Berlin*, No. 19, p. 13, 1934.

²⁵ *Ibid.*, p. 275.

²⁷ *Ap. J.*, **76**, 313, 1932.

The star α^1 CVn, of magnitude 5.39, is 20'' distant in position angle 228°. Leonard¹⁹ gives its spectral type as F2; a recent β plate indicates that its classification on the MKK system is F5 IV. The star is probably a spectroscopic binary of small range. Spectrograms of α^1 and α^2 CVn are reproduced in Figure 11.

15. ω *Ophiuchi* = HD 148898.—The *Draper* type is F0, but the spectrum is nearly identical with that of ι Cas (A5p) except for λ 4078 and λ 4215 of *Sr* II, which are always stronger in the latter star. The K line has the same strength as in ι Cas at *Ca* II maximum. Morgan²⁴ has reported changes in λ 4215. Six β plates strongly suggest that this line varies and that changes also occur in K, λ 4137, and some other lines as well.

16. 21 *Aquilae* = HD 179761.—The spectrum is of type B8. Morgan^{25, 28} has reported variations in the intensity and appearance of λ 4121 and λ 4471 of *He* I. Four β plates reveal no definite changes, but this evidence is inconclusive.

17. γ *Equulei* = HD 201601.—The *Draper* type is F0p, the peculiarity noted being the strength of *Sr* II 4078. This line and the other component of the resonance doublet, at λ 4215, are stronger in γ Equ than in any of the known spectrum variables. The lines of *Cr* II are somewhat weaker than in the peculiar stars of earlier type, and *Eu* II is stronger. The spectrum resembles that of β *Coronae Borealis*, which has recently been studied under high dispersion by W. A. Hiltner.²⁹ Morgan²⁴ has reported changes in *Cr* II 4558; three β plates reveal no changes, but the number of plates is far too small to establish nonvariability.

IV. CATALOGUE OF SPECTRUM VARIABLES

It seems desirable at this time to compile a first catalogue of spectrum variables which will summarize the present state of knowledge concerning the gross spectroscopic characteristics of these stars. Table 7 is such a compilation. It lists twenty stars, of types B8–F0, in which changes in the absorption lines have been observed.

The first six columns are self-explanatory; the positions and magnitudes are those of Schlesinger's *Bright Star Catalogue*. The seventh column gives the strongest peculiar features which distinguish each spectrum. The symbols have the following significance:

Cr means that λ 4078 and λ 4171 of *Cr* II are strong;
Eu means that λ 3930 and λ 4205 of *Eu* II are strong;
Mn means that λ 4206 and λ 4253 of *Mn* II are strong;
Si means that λ 4128 and λ 4131 of *Si* II are strong;
Sr means that λ 4078 and λ 4215 of *Sr* II are strong;
 λ 4137 means that $\lambda\lambda$ 3944, 4137, and 4282 are strong;
 λ 4200 means that $\lambda\lambda$ 3955, 3992, and 4200 are strong.

It is assumed that *Cr* II is the principal contributor to λ 4078 in spectra where *Cr* II 4171 is strong but λ 4215 is weak or absent; where λ 4215 is strong, λ 4078 is attributed mainly to *Sr* II.

The eighth and ninth columns give the lines which vary. Since all the lines of a given ion appear always to vary together, it is sufficient merely to name the ion which is the source of variable lines of known origin. Unidentified lines are indicated by their wave lengths. The variable lines are grouped into two classes: I, those which vary in phase with *Ca* II K, and II, those which vary out of phase with K. Where the variation of K has not been observed, this classification is, of course, ambiguous. Lines whose variation requires further verification are inclosed in parentheses; these have probably been too liberally employed, and I should estimate that more than 80 per cent of the lines so distinguished are truly variable. The elements of variation are compiled. The periods are probably correct to within two units in the last decimal place; exceptions are the periods distinguished by parentheses, which require further verification.

²⁸ *A. J.*, 77, 226, 1933.

²⁹ *A. J.*, 102, 438, 1945.

TABLE 7
A FIRST CATALOGUE OF SPECTRUM VARIABLES

No.	Star	R.A. 1900	DECL. 1900	Mag. Vis.	HD		PECULIAR FEATURES	LINES OF CLASS I. (LINES WHICH VARY WITH K)	LINES OF CLASS II (LINES WHICH VARY OPPOSITE K)	ELEMENTS OF VARIATION		
					Number	Type				Phase	Epoch (J.D.)	Period
1..	α And	0 ^h 03 ^m 2	+28° 32'	2.15	358	A0p	<i>Mn</i> , λ 4137	<i>Ca</i> II, λ 4161; (<i>Cr</i> II), (<i>Mg</i> II)	(<i>Eu</i> II), $\lambda\lambda$ (4063), (4179)	<i>Cr</i> II min.	2431782.5	(2.607)
2..	γ Ari (S)	1 48.0	+18 48	4.83	11503	A0p	<i>Cr</i> , <i>Eu</i> , <i>Si</i>	<i>Ca</i> II, <i>Sr</i> II, $\lambda\lambda$ 4133, 4161, 4423, 4431; (<i>Cr</i> II), (λ 4290)	(λ 4179)	<i>Ca</i> II max.	2431700.1	1.740
3..	ι Cas	2 20.8	+66 57	4.59	15089	A5p	<i>Sr</i> , <i>Cr</i>	λ 4200; $\lambda\lambda$ (3955), (3992), (4129)	<i>He</i> I	<i>He</i> I max.	2432227.55	2.563
4..	56 Ari	3 06.3	+26 53	5.65	19832	A0p	<i>Si</i> ?, λ 4200	<i>Ca</i> II, <i>He</i> I; (<i>C</i> II), (<i>Mg</i> II)	$\lambda\lambda$ 3955, 3992, 4057, 4200; (<i>Fe</i> II)	<i>He</i> I max.	2431334.90	2.4660
5..	+33°1008	5 12.4	+33 39	5.39	34452	A0p	<i>Si</i> , λ 4200	(<i>Cr</i> II), (<i>Cr</i> I), (<i>Sr</i> II)				
6..	θ Aur	5 52.9	+37 12	2.71	40312	A0p	<i>Si</i>	(<i>Eu</i> II), (<i>Sr</i> II)				
7..	49 Cnc	8 39.3	+10 27	5.58	74521	A0p	<i>Si</i> , <i>Cr</i> , <i>Eu</i>	(<i>Cr</i> II), (<i>Sr</i> II)				
8..	17 Com	12 23.9	+26 28	5.38	108662	A0p	<i>Si</i> , <i>Cr</i> , <i>Eu</i>	(<i>Cr</i> II), (<i>Sr</i> II)				
9..	21 Com	12 26.0	+25 07	5.39	108945	A3p	<i>Sr</i> , <i>Cr</i>	(<i>Sr</i> II)				
10..	ϵ UMa	12 49.6	+56 30	1.68	112185	A0p	<i>Cr</i> , <i>Eu</i>	<i>Ca</i> II	<i>Cr</i> II, <i>Cr</i> I, <i>Fe</i> II, <i>Fe</i> I, <i>Mn</i> II, <i>Mn</i> I; (<i>Sr</i> II), (<i>Ti</i> II), (<i>Ni</i> II), (<i>Si</i> II), (<i>O</i> I)	<i>Ca</i> II min.	2426437.01	5.0887
11..	α^2 CVn	12 51.4	+38 51	2.90	112413	A0p	<i>Si</i> , <i>Cr</i> , <i>Eu</i>	<i>Ca</i> II, <i>Ti</i> II, <i>Mn</i> II, <i>Sr</i> II, <i>Eu</i> II, <i>Gd</i> II, <i>Dy</i> II, <i>Ce</i> II, <i>Pr</i> II, <i>Nd</i> II, <i>Sm</i> II, <i>Fe</i> I, <i>Ni</i> I; (<i>Cr</i> I)	<i>Cr</i> II, λ 4200; (<i>Fe</i> II)	<i>Eu</i> II max.	2419869.720	5.46939

TABLE 7—Continued

No.	Star	R.A. 1900	DECL. 1900	MAG. Vis.	HD		PECULIAR FEATURES	LINES OF CLASS I (LINES WHICH VARY WITH K)	LINES OF CLASS II (LINES WHICH VARY OPPOSITE K)	ELEMENTS OF VARIATION		
					Number	Type				Phase	Epoch (J.D.)	Period
12..	78 Vir	13 ^h 29 ^m .1	+ 4°10'	4.93	118022	A2p	<i>St</i> , <i>Cr</i> , <i>Eu</i>	<i>Ca</i> II <i>Ca</i> II, <i>Cr</i> II, <i>Mg</i> II, λ 4161, λ 4290; (<i>Sr</i> II), (<i>Fe</i> II), (<i>Si</i> II), (<i>Cr</i> I)	(<i>Cr</i> II), (<i>Sr</i> II) <i>Eu</i> II, λ 4063, λ 4296	 <i>Eu</i> II max.	 2430143.07	 9.295
13..	—18°3789	14 13.1	—18 15	5.74	125248	A0p	<i>Cr</i> , <i>Eu</i>	<i>Ca</i> II, λ 4137; λ (3944), (3984), (4282)	λ 4253; (λ 4206)	 <i>Mn</i> II max.	 2421391.45	 (2.2445)
14..	π Boo(A)	14 36.0	+16 51	4.94	129174	A0	<i>Mn</i> , λ 4137	<i>Ca</i> II (<i>Ca</i> II), (<i>Sr</i> II) <i>Ca</i> II, (<i>Mg</i> II) (<i>He</i> I)	<i>Sr</i> II, λ 4161, λ 4290 (<i>Cr</i> II)	 <i>Sr</i> II max.	 2432003.85	 2.675
15..	χ Ser	15 37.1	+13 10	5.26	140160	A0p	<i>St</i> , <i>Cr</i>	.....	.....	.....	.....	.....
16..	ω Oph	16 26.2	—21 15	4.57	148898	F0	<i>St</i> , <i>Cr</i>	.....	.....	.....	.....	.....
17..	45 Her	16 42.8	+ 5 26	5.28	151525	A0p	<i>Cr</i>	.....	.....	.....	.....	.....
18..	21 Aql	19 08.7	+ 2 07	5.10	179761	B8	.....	.....	.....	.....	.....	.....
19..	73 Dra	20 32.8	+74 37	5.18	196502	A2p	<i>St</i> , <i>Cr</i> , <i>Eu</i>	<i>Eu</i> II, <i>Ti</i> II; (λ 4423)	.....	.....	.....	.....
20..	γ Equ	21 05.5	+ 9 44	4.76	201601	F0p	<i>St</i> , <i>Eu</i>	(<i>Cr</i> II)	.....	<i>Eu</i> II max.	 2430678.22	 20.27

NOTES FOR TABLE 7

1. Sp.bin., $P = 9647$; 10.8 mag. (var?) comp., 80", 280°.
2. 4.75 mag. comp., A0, 8", 0°, c.p.m.
3. 6.8 mag. comp., F6, 2", 250°, 8.0 mag. comp., G4, 7", 111°.
4. From Verkes and Perkins (1946-47) plates.
5. 7.5 mag. comp., 3", 330°.
6. 7.5 mag. comp., A-met-l., 145", 250°, c.p.m.
7. 6.7 mag. comp., A-met-l., 145", 250°, c.p.m.
8. 6.7 mag. comp., A-met-l., 145", 250°, c.p.m.
9. Sp.bin.?, $P = 4715$; in Ursa cluster.
10. 5.39 mag. comp., F5 IV, 20", 228°, Sp.bin., c.p.m.
11. In Ursa cluster.
12. 5.81 mag. comp., A-met-l., 6", 105°.
13. In Ursa cluster.
14. 11 mag. comp., 2", 270°.

Inspection of the table shows that the periods appear to be uncorrelated with other characteristics. The variable lines are seen usually to include those strong lines which mark the spectrum as peculiar, except in the case of Si II, which usually does not vary.

Table 8 sets forth the phase relations among lines of different ions in each of the stars in Table 7. Included are all lines or sets of lines which are found to vary in three or more of the stars. The stars are arranged approximately in order of increasing effective excitation, according to the system elucidated by Morgan.³⁰ The columns are arranged in order of increasing ionization potential. The notation is the same as in Table 7. The table in-

TABLE 8*
PHASE RELATIONS AMONG VARIABLE LINES IN SPECTRUM VARIABLES

Source	Cr I	Sr II	Eu II	Ca II	Ti II	Mg II	Mn II	Fe II	Cr II	He I	λ 4161	λ 4200	λ 4290
I.P. (e.v.)	6.7	11.0	11.2	11.8	13.6	15.0	15.6	16.2	16.6	24.5	.....	.....	.....
21 Aql													
56 Ari										II		I	
+33°1008				I		(I)		(II)		I		II	
α And													
π Boo (A)				I			II						
θ Aur	(I)	(I)							(I)				
45 Her				I		(I)			(II)				
ϵ UMa	II	(II)		I	(II)		II	II	II				
α^2 CVn	(I)	I	I	I	I		I	(II)	II			II	
49 Cnc		(I)	(I)										
17 Com		(I)							(I)				
78 Vir		(II)		I				(II)	(II)				
γ Ari(S)			(II)	I		(I)		(II)	(I)		I		
-18°3789	(I)	(I)	II	I		I		(I)	I		I		I
21 Com		I											
ι Cas		(I)		I				(II)	(I)		I		(I)
ω Oph		(I)		(I)									
73 Dra			I		I								
χ Ser		II		I							II		II
γ Equ									(I)				

* Lines of class I vary with K; lines of class II vary opposite K. The classification is ambiguous in spectra where the variation of K has not been observed. Parentheses indicate that the variation requires verification.

indicates six well-established cases in which the phase relations differ from star to star among lines of pairs of ions. These cases are as follows:

1. In α^2 CVn, Eu II and Ca II vary in phase; in BD-18°3789, they vary out of phase.
2. In ι Cas and α^2 CVn, Sr II and Ca II vary in phase; in χ Ser, they vary out of phase.
3. In BD-18°3789, Ca II and Cr II vary in phase; in ϵ UMa and α^2 CVn, they vary out of phase.
4. In α^2 CVn, Ca II and Mn II vary in phase; in π Boo(A) they vary out of phase.
5. In ι Cas, Ca II and λ 4161 vary in phase; in χ Ser, they vary out of phase.
6. In ϵ UMa, Cr II and Mn II vary in phase; in α^2 CVn, they vary out of phase.

Table 8 suggests that in each star all lines originating from atoms or ions having ionization potentials within certain limits vary together, while lines originating from atoms or ions of lower or higher ionization potential vary in the opposite sense. Thus, in α^2 CVn, the lines of class I originate from atoms or ions having ionization potentials less than 16 volts, and those of class II originate from atoms or ions having ionization potentials

³⁰ *A. J.*, 77, 330, 1933.

greater than 16 volts. Two exceptions appear in the table. The first is BD +33°1008; but here the rule would be preserved if it were assumed that the unidentified line at λ 4200 has a source of ionization potential between 16 and 24 volts. The second exception is γ Ari (S), and this can be reconciled with the proposed rule only if the observations are in error.

V. LUMINOSITIES AND COLORS

A careful comparison of the spectra of the known spectrum variables with the spectra of other peculiar stars on the observing list fails to reveal any criterion, except the variability itself, by which they can be distinguished. There are a number of cases in which the spectrum of a star not known to vary matches almost identically, at some phase, that of one which does vary (e.g., 10 Aql and ι Cas). It is to be expected that continued observation will reveal many new cases of variability among such spectra, and it is by no means impossible that all the peculiar A stars will eventually prove to be spectrum variables of greater or smaller amplitude.

In view of the spectroscopic identity of the variable and (apparently) nonvariable peculiar A stars, it appears legitimate to discuss their luminosities and colors together. The data are very meager at best, and the admission of all peculiar A stars alleviates this deficiency in an important degree.

1. *Luminosities.*—The peculiar A stars generally exhibit less strongly winged hydrogen lines than do main-sequence stars of the same spectral type. The effect is not large, but it appears to be real. The application of the other usual luminosity criteria in the discussion of peculiar stars later than type A2 is probably not legitimate, since some of the lines involved are those which mark the spectrum as peculiar.

The distances probably most accurately known are those of ϵ UMa, χ Ser, and 78 Vir, which are assumed to be members of the Ursa cluster. Smart's recent discussion³¹ give absolute magnitudes of -0.32 for ϵ UMa (A0p), $+0.41$ for χ Ser (A0p), and $+0.47$ for 78 Vir (A2p). The corresponding mean absolute magnitudes are $+0.81 \pm 0.41$ for nine cluster stars of (normal) type A0 and $+1.51 \pm 0.42$ for seven cluster stars of (normal) type A2. The errors indicated are average residuals for single stars. It follows that ϵ UMa and 78 Vir, at least, probably lie appreciably above the main sequence. Moreover, the effective excitation in the spectrum of χ Ser corresponds to a type certainly later than A0, so that this star, too, must lie above the main sequence.

The two spectrum variables in the Coma cluster present a similar case, if somewhat less convincing. According to Trumpler's value³² of the parallax ($0''.012$), 17 Com (A0p) has an absolute magnitude of $+0.83$, and 21 Com (A3p) of $+0.84$. The effective excitation in both spectra is definitely later than in type A0, so that both these stars probably lie at least slightly above the main sequence.

Among all the peculiar stars on the observing list, there are thirteen for which Schlesinger³³ gives a trigonometrical parallax of $0''.020$ or greater. These stars are listed with their parallaxes, according to Schlesinger, in Table 9. The first four columns require no explanation; the fifth column gives the absolute magnitude, $M(p)$, derived from the magnitude and parallax. The probable error given is $2.17 \Delta p/p$, where p is the parallax and Δp its probable error. The use of this formula is not strictly legitimate here because of the large values of $\Delta p/p$, but it provides a useful approximation. The sixth column gives the difference between the absolute magnitude of the fifth column and the absolute magnitude, M_0 , of a main-sequence star of corresponding spectral type. The values of M_0 have been taken from Trumpler's work.³²

It is readily seen that a normal distribution of the errors in p produces a skew distribution of the errors in $M(p)$ such that $M(p)$ is probably too faint. Since this is the case,

³¹ *M.N.*, **99**, 448, 710, 1939.

³² *Lick Obs. Bull.*, **14**, 157, 1930.

³³ *General Catalogue of Parallaxes* (2d ed.; Lancaster, Pa., 1935).

the difference $M(p) - M_0$ is probably too great. Moreover, since this is true for each star, it is also true of the weighted mean, $\overline{M(p)} - \overline{M_0}$. Using weights proportional to the inverse squares of the probable errors of M_0 , we thus find that $\overline{M(p)} - \overline{M_0} = -0.56 \pm 0.14$ (p.e.), i.e., on the average these stars probably lie more than half a magnitude above the main sequence.

The arbitrary exclusion from the table of all measured parallaxes less than $0''.020$ introduces an error which arises from the circumstance that parallaxes whose true values are less than this limit but whose measured values exceed it are included, while those whose true values exceed the limit but whose measured values fall below it are excluded. The effect of this cutoff error will be seen, however, to include stars whose $M(p)$ is too faint and to exclude those whose $M(p)$ is too bright. We may therefore regard 0.5 mag. as a kind of lower limit of the distance from the main sequence upward to the peculiar stars.

TABLE 9
TRIGONOMETRICAL PARALLAXES AND ABSOLUTE MAGNITUDES OF PECULIAR STARS

Star	HD Type	m	Trigonometrical Parallax (p)	$M(p)$	$M(p) - M_0$	Corrected Parallax
β Tau.....	B8	1.78	$0''.022 \pm 0''.007$	-1.51 ± 0.69	-1.3	$0''.055 \pm 0''.017$
α And.....	A0p	2.15	$.024 \pm .005$	-0.95 ± 0.45	-1.8	$.043 \pm .009$
+73°2743.....	A0p	5.38	$.023 \pm .009$	$+2.19 \pm 0.85$	+1.3	$.181 \pm .071$
μ Lep.....	A0p	3.30	$.021 \pm .007$	-0.09 ± 0.72	-1.0	$.063 \pm .021$
θ Aur.....	A0p	2.71	$.021 \pm .006$	-0.68 ± 0.62	-1.7	$.048 \pm .014$
α^2 CVn.....	A0p	2.90	$.025 \pm .005$	-0.11 ± 0.43	-1.0	$.063 \pm .013$
ω Her.....	A0p	4.53	$.033 \pm .006$	$+2.12 \pm 0.39$	+1.2	$.175 \pm .032$
108 Aqr.....	A0p	5.32	$.020 \pm .010$	$+1.83 \pm 1.08$	+0.9	$.153 \pm .077$
κ Psc.....	A2p	4.94	$.035 \pm .006$	$+2.66 \pm 0.37$	+1.0	$.156 \pm .027$
ι Cas.....	A5p	4.59	$.022 \pm .009$	$+1.30 \pm 0.89$	-1.0	$.063 \pm .026$
ω Oph.....	F0	4.57	$.033 \pm .008$	$+2.16 \pm 0.53$	-0.7	$.071 \pm .017$
γ Equ.....	F0p	4.76	$.022 \pm .006$	$+1.47 \pm 0.59$	-1.4	$.052 \pm .014$
β CrB.....	F0p	3.72	0.033 ± 0.005	$+1.31 \pm 0.33$	-1.6	0.048 ± 0.007

Since there appears to be no systematic change of $M(p) - M_0$ with spectral type, we may now proceed on the assumption that $M - M_0$ is a constant for the peculiar stars. Consider the case of two stars whose spectral types and measured parallaxes are identical but whose apparent magnitudes differ appreciably. If we assume that the $M(p)$ of the brighter star is correct, then the true parallax of the fainter star must be much less than its measured value. However, if we assume that the $M(p)$ of the fainter star is correct, then the true parallax of the brighter must be much greater than its measured value. It is readily shown that the first alternative has an appreciably greater a priori probability than the second and that selection effects operate in the same sense. We must therefore weight most heavily the stars of brighter apparent magnitude. This can be achieved by correcting all the parallaxes to the values for which $m = M_0$. The seventh column of Table 9 gives these corrected parallaxes with their probable errors. If we now take the weighted mean of these, we find that $\bar{p} = 0''.057 \pm 0''.004$ (p.e.); the corresponding value of $M - M_0$ is then found to be -1.22 ± 0.15 (p.e.). From the manner in which this value is derived, it follows that we may regard it as a kind of upper limit to the distance from the main sequence upward to the peculiar stars.

The most serious weakness in this argument would seem to be the uncertainty of the *Draper* types, which are very probably not correct for some of the stars. It is unlikely, however, that the classification errors are sufficiently systematic to produce the whole effect which is found. We therefore conclude that the peculiar stars, as a group, lie about 1 mag. above the main sequence.

2. *Colors*.—Reference has been made to the catalogue of color indices compiled by Öpik³⁴ from various published determinations. The catalogue gives colors for 654 stars. The scale is slightly more extended than the Harvard scale. Each color is given a weight by Öpik; he states that the unit of weight corresponds to a probable error of ± 0.06 mag.

The colors of the twenty stars on the observing list which are given by Öpik are collected in Table 10, together with their weights. The letter "c" in the weight column indicates that the components of a visual binary have been measured together. The stars are arranged approximately in order of increasing effective excitation.³⁰ Table 11 gives the relation between *Draper* type and color deduced by Öpik from the whole material of his catalogue.

TABLE 10
COLORS OF PECULIAR A STARS (AFTER ÖPIK)

Star	C.I.	Wt.	HD	Star	C.I.	Wt.	HD
+3°2867.....	−0.25	2	A0p	ε UMa.....	−0.14	7	A0p
α And.....	−.23	5	A0p	α ² CVn.....	−.29	5	A0p
π Boo.....	−.26	2c	A0	γ Ari.....	−.39	2c	A0p
β Tau.....	−.23	5	B8	κ Psc.....	−.14	3	A2p
κ Cnc.....	−.18	4	B8	ω Her.....	−.16	3	A0p
ν Her.....	−.21	3	B9	52 Her.....	−.09	2	A2p
φ Her.....	−.24	4	B9p	78 Vir.....	−.12	4	A2p
11 Ori.....	−.20	3	B9	ι Cas.....	+ .01	2	A5p
θ Aur.....	−.15	5	A0p	73 Dra.....	−.10	2	A2p
φ Dra.....	−0.22	2	A0p	χ Ser.....	+0.06	3	A0p

TABLE 11
RELATION BETWEEN DRAPER TYPE AND COLOR (AFTER ÖPIK)

	HD TYPE								
	B3	B5	B8	B9	A0	A2	A3	A5	F0
C.I.....	−0.27	−0.24	−0.20	−0.17	−0.11	−0.03	+0.05	+0.06	+0.16

If we reject the colors of π Boo and γ Ari (in which cases the components were measured together), we find that the weighted mean color index of the eight remaining A0p stars in Table 11 is -0.18 , which corresponds to type B9. This value for the mean color is somewhat reduced if we exclude χ Ser, which is obviously of lower excitation than the other A0p stars. The weighted mean of the remaining seven A0p stars then is -0.20 , which corresponds to type B8. Still excepting χ Ser, we see, further, that every one of the A0p stars has a bluer color than the normal A0 star. Similarly, each of the four A2p stars is bluer than the normal A2 star, and ι Cas is bluer than the normal A5 star.

Notwithstanding the low weight of some of these colors, the evidence must be regarded as conclusive that the peculiar A stars, as a group, are bluer than the normal A stars of equivalent spectral type. There remains, however, the possibility that the bluer colors may not reflect higher color temperatures but may be due only to the weakening, already mentioned, of the Balmer lines in the blue and violet. That this is not the case is indicated by the Greenwich gradients³⁵ of five of the stars in Table 10. These are α And,

³⁴ *Pub. Obs. U. Tartu* (Dorpat), 27, 3, 1929.

³⁵ *M.N.*, 100, 189, 1940.

-0.10 ; θ Aur, -0.05 ; ϵ UMa, -0.05 ; α^2 CVn, -0.06 ; and π Boo, $+0.06$. The gradients are measured relative to the mean of nine A0 stars, and their probable error is given as ± 0.02 . In the case of π Boo, the components were measured together, so that its gradient can be rejected. The remaining four gradients all indicate color temperatures significantly higher than in a normal A0 star.

Additional evidence for the excessive blueness of the peculiar A stars is provided by the photoelectric colors which Stebbins and Whitford have given³⁶ for two peculiar stars. One is α^2 CVn, for which the $V - I$ index is -2.12 ; the other is 108 Aquarii, for which $V - I = -2.11$. Both these stars are of type A0p. The mean color index for A0 stars is given as -1.80 , and for B5 stars as -2.24 . The base-line for the $V - I$ indices is so long that these deviations from normal color cannot possibly be attributed to a luminosity weakening of the hydrogen lines.

In conclusion, we may note that the normal stars of type B8 are about 1 mag. brighter than the normal stars of type A0. It is therefore highly suggestive that the A0p stars, as a group, are also about 1 mag. brighter than the A0 stars and have colors corresponding to type B8. One is tempted to regard an A0p star as an object having the gross characteristics of a B8 star, but one in whose atmosphere some unknown mechanism suppresses the lines of helium and enhances those of hydrogen and of one or more of the ions whose lines mark the spectrum as peculiar: *Si* II, *Sr* II, *Cr* II, *Mn* II, and the rare earths.

I wish to acknowledge the kind assistance of Dr. W. W. Morgan, who has largely directed the course of this investigation. I am also indebted to Dr. O. Struve for his permission to refer to many spectrograms in the files of the Yerkes and McDonald Observatories; to Dr. J. L. Greenstein for the CG plates of ι Cas and for the CQ plate of 17 Com (B); and to Dr. G. P. Kuiper for illuminating discussions on the subject of the absolute magnitudes of the peculiar stars. Grateful acknowledgment is also made to my wife, who has given much help in the preparation of the manuscript and illustrations.

³⁶ *Ap.J.*, 102, 318, 1945.

